Shell Exploration & Production

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Subject: Selection of Low and High Condition Currents for Drilling Discharge Modeling

The purpose of this memo is to verify that the selection of the mean and maximum Chukchi Sea current speeds used for mud drill cuttings discharge modeling meets EPAs guideline of capturing a low current speed condition and a high current speed condition.

In accordance with guidance shared with Shell during a meeting on December 5, 2014, EPA noted that the modeling needs to look at a range of currents, and the permit specifically says that this is should be a low-high range. EPA asked why Shell used the mean and max currents in the modeling reports, rather than a low and a high. EPA indicated that they generally require a 10 percentile current speed, and a 90 percentile current speed to meet the low and high conditions, respectively.

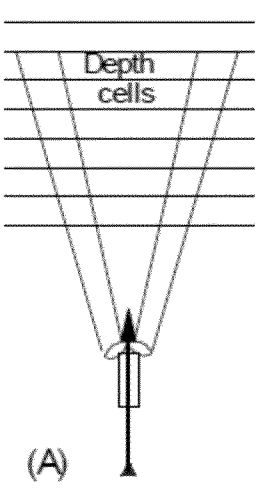
The Offshore Operators Committee (OOC), a consortium of companies operating in the waters of the Gulf of Mexico, sponsored the development of a model to predict the fate of drilling fluids discharged into the offshore environment (Brandsma and Smith 1999, Alam and Brandsma 2013). The OOC model predicts the fate of drilling fluids, drill-cuttings, or produced water discharged from a single discharge point. Particulates may be solids or droplets.

A series of modeling exercises was conducted in order to understand the range of discharge conditions expected for the 2015 drilling season. These conditions include the discharge characteristics of the drillship Noble Discoverer and the drill rig Transocean Polar Pioneer that will be used for drilling in the Burger Prospect (e.g. flow rate, discharge pipe diameter, location of discharge points below water surface), the well design, and the expected range of conditions for water temperature, wind speeds, currents, and salinity.

The UAF publication "Physical Oceanographic Measurements in the Klondike and Burger Survey Areas of the Chukchi Sea: 2008 and 2009" by Weingartner and Danielson (2010) was used to characterize current speeds for the modeling. A current speed of 7 cm/s (denoted as mean) and a current speed of 25 cm/s (denoted as maximum) were chosen as estimates for the low and high conditions, respectively, which may differ somewhat from the definitions of low (10 percentile) and high (90 percentile) conditions according to EPA recommendations.

To investigate that these current speeds do meet the low and high conditions suggested by EPA, the Acoustic Doppler Current Profiler (ADCP) data from the Ice Profiling Sonar program were

assembled for the statistical analysis of current speed and direction at the Burger Prospect in the US Chukchi Sea (Shell Metocean Memorandum by Raye, 2013).



ADCPs measure the water velocity (speed and direction) in depth bins similar to the illustration to the left. Care should be exercised when considering data from the shoulder months, where ice cover may be present. Surface sea ice will most likely contaminate the shallower depth bins, while ice keels can impact depth bins. These do not aptly describe the currents and are a mix of currents, ice movement, and backscatter interference. However, for purposes of discharge modeling, only currents measured during the open water season were considered.

Site-specific current measurements at Burger cover the continuous period from October 2008 through August 2012 (3.8 years) with minimal gaps during mid-summer instrument servicing.

Directionally, currents in the earlier part of the open water season tend to flow towards the north to east sector (0-90°). Later in the season, the current direction becomes more variable, with strong components in the west to southwest direction. There is a considerable directional alignment throughout the water column, and the overall net transport during the open season is to the northeast.

Bin depths of 7.7m and 35.7m were chosen to characterize the near surface and near seafloor current velocity, while the 15.7 and 23.7m bins represent the mid-water column. Current speeds representing the low (10 percentile) and high (90 percentile) case estimates for the open water season for each of the bins mentioned above, are shown in Table 1 below.

Table 1: Current speeds representing low and high case estimates for the open water season (July through November)

Water Depth, m	Low Case: 10 percentile non-exceedance[1]		High Case: 90 percentile non-exceedance[1]		Overall net transport direction, °True North
	Current Speed per bin, cm/s	Depth-averaged current speed, cm/s	Current Speed per bin, cm/s	Depth-averaged current speed, cm/s	
7.7	6.2	6.0	29.2	25.5	NE (45°)
15.7	6.2		26.2		
23.7	6.0		24.1		
35.7	5.7		22.3		

[1] Current speeds do not exceed a specified value

The analysis has revealed some discrepancies in the choice of currents speeds, in particular for the low condition where the 10 percentile current speed is 14% less than the current speed used in the modeling (6 cm/s versus 7 cm/s). These differences are likely due to i) the site-specific measurements at Burger versus the wider geographical area transects that include Klondike and

Burger, and ii) the dataset length, as the 3.8 years versus 2 years of data afford a more robust statistical analysis.

To quantify the OOC model's sensitivity to initial conditions, Shell conducted an additional modeling exercise for the Transocean Polar Pioneer where the site-specific, depth-varying 10 percentile and 90 percentile current speeds were applied to initiate the model runs.

The model results for the two sets of current speeds (mean/max, low/high) were compared against each other. A number of different output parameters and their respective percent of change are shown in the Table 2 below.

Table 2: Example comparison of model output parameters for the mean/max and low/high current speed conditions for Transocean Polar Pioneer

Parameter	Current Speeds Used in Modeling				% of change "-" reduction "+" increase
	Initial Choice		EPA Guidelines		
	Mean (depth averaged 7 cm/s)	Max (depth averaged 25 cm/s)	10 percentile (depth varying 5.7-6.2 cm/s)	90 percentile (depth varying 22.3-29.2 cm/s)	
Area affected by solid deposit thickness ≤ 1 cm	0.512 ha	0.988 ha	0.471 ha	0.997 ha	-8% for low +1% for high
Solid deposit thickness at 100 m from the source	1-3 cm	3-10 cm	1-3 cm	3-10 cm	No change
Solid deposit thickness at 300 m from the source	< 1 cm	< 1 cm	< 1 cm	< 1 cm	No change
TSS concentration at 100 m from the source	5.0 to 244.9 mg/l	7.2 to 256.2 mg/l	4.8 to 240.4 mg/l	10.8 to 248.2 mg/l	-4% to +2% for low +50% to -3% for high
TSS concentration at 300 m from the source	1.4 to 112.6 mg/l	2.4 to 92.1 mg/l	1.2 to 105.5 mg/l	2.4 to 94.0 mg/l	-14% to -6% for low 0% to +2% for high

Based on these results, Shell believes that the value of 7 cm/sec is representative of the low current speed condition, and 25 cm/sec is representative of the high current speed condition. Therefore the modeling reports submitted to USEPA as part of Shell's NOI applications do not need to be modified.